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No color-morphology bimodality of AGN host galaxies

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Abstract.

It is still a matter of debate whether the properties of galaxies hosting an Active Galactic Nucleus (AGN) are different from the properties of quiescent galaxies. We constructed a sample of ~ 50 AGN at a mean redshift of $\langle z \rangle \approx 0.6$ that lack a detectable optical nucleus. This characteristic allows to study the properties of the host galaxies with much higher accuracy than in the case of “normal” AGN which show a prominent central point source in optical images. A comparison sample of X-ray faint, quiescent galaxies at intermediate redshifts shows a clear bimodality in terms of both rest-frame colors and morphological concentration indicators. In contrast to this, the AGN host galaxies comprise a large fraction of objects that have *early-type morphologies but relatively blue rest-frame colors*, possibly due to recent or ongoing star formation. A fraction of the “optically dull” AGN in our sample show evidence for kpc-scale absorption; low Supermassive Black Hole accretion rates are more likely in other cases.

1. Introduction

During the last years, growing evidence has been collected that Supermassive Black Holes (SMBHs) play an important role in the formation and evolution of the galaxies they reside in. Massive black holes have been detected in practically all large spheroidal galaxies that are nearby enough to resolve their central kinematics at intrinsically small spatial scales. Hence, most galaxies with a spheroidal component might undergo a phase during which the SMBH accretes matter and is observed as an Active Galactic Nucleus (AGN). It is however still an open question whether the spectrophotometric and/or morphological properties of AGN hosts are different from those of the quiescent galaxy population.

Usually, it is a complicated matter to study galaxies harboring an active nucleus due to the bright central point source. A very good modelling of the Point Spread Function is crucial to analyse the light profile of the host galaxy, in particular at intermediate and high redshifts (e.g. Sánchez et al. 2004). Here, we will utilise a sample of AGN *without a detectable optical nucleus* to study the host colors and morphologies much more robustly than it would be feasible for “optically normal” AGN.

2. Sample Selection

For the construction of our sample, we combined deep ground-based multi-color photometry from COMBO-17 (Wolf et al. 2003), HST/ACS imaging from the

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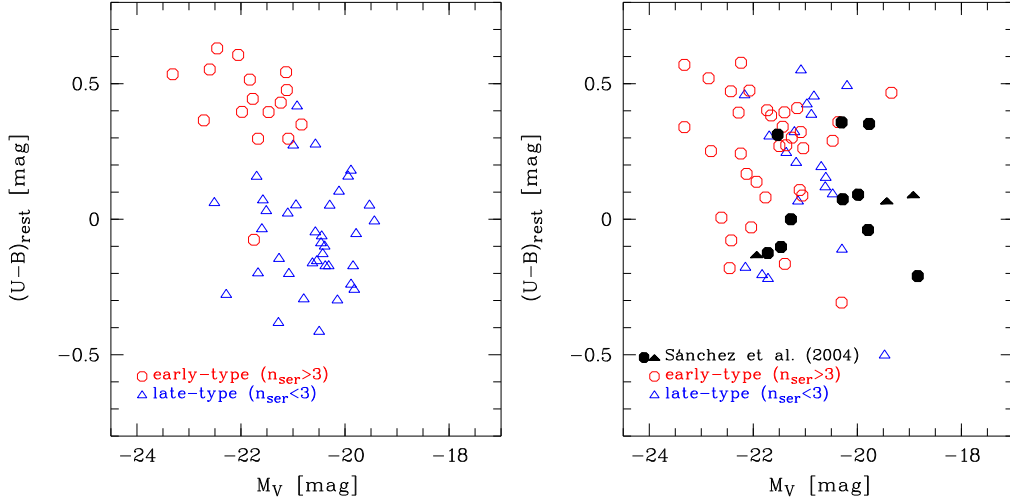


Figure 1. *left:* color-magnitude diagram of quiescent galaxies at redshifts $\langle z \rangle \approx 0.6$. Early- and late-type morphologies are indicated by circles and triangles, respectively. *right:* our sample of AGN at the same redshifts (open symbols). For comparison, the type-1 AGN (with prominent optical nuclei) from Sánchez et al. (2004) are depicted by solid symbols. A flat cosmology with $\Omega_\lambda = 0.7$, $\Omega_m = 0.3$ and $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$ has been assumed.

GEMS survey (Rix et al. 2004) and the X-ray point source catalogue of the (Extended) Chandra Deep Field South (CDFS, Giacconi et al. 2002; Lehmer et al. 2005). We pre-selected X-ray detections with unambiguous optical counterparts and X-ray luminosities that indicate an accreting SMBH. All objects classified as broad-line (type-1) AGN either in the COMBO-17 photo-z catalogue or on the basis of optical spectra from Szokoly et al. (2004) were *rejected*. Using the GALFIT package by Peng et al. (2002), we also performed 2-D light profile fits and tossed all galaxies from the data set that showed even only a *potential* central point source ($\geq 10\%$ of the total flux) in the ACS F606 or F850 images.

The remaining sample holds 53 objects in the range $0.3 < z < 1.2$ with a median of $\langle z \rangle \approx 0.6$. More than 90% of the optical spectra either show emission lines that can be attributed entirely to star formation, or no emission lines at all (“optically dull” AGN, e.g. Moran et al. 2002). However, for the majority of the objects, no spectra are available, hence a fraction of these might be narrow-line AGN. As a quiescent comparison sample, we selected COMBO-17 galaxies at the same redshifts that were not detected in X-rays. Note that exactly the same morphological de-selection criteria as for the AGN were applied to these objects.

3. Results and Discussion

Fig. 1 shows the color-magnitude diagrams of the quiescent galaxies (left panel) and the AGN hosts (right panel). In the case of the former, the “blue cloud” and a “red regime” are well separated. Moreover, the objects are equally separated by morphological type (objects with a Sérsic index $n_{\text{ser}} > 3$ are classified as early-types, those with $n_{\text{ser}} < 3$ as late-types). In contrast, the AGN sample

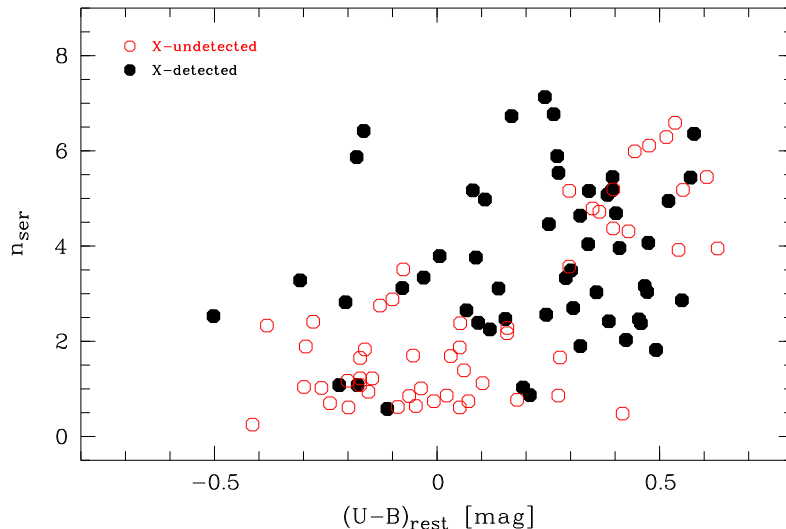


Figure 2. Sérsic index versus rest-frame $U-B$ color for the quiescent galaxy sample (open circles) and the AGN hosts (solid circles).

comprises early-type galaxies with relatively blue colors as well as late-types with relatively red colors – the AGN hosts do not populate two distinct regimes in color-magnitude space. A similar result has been found by Sánchez et al. (2004) for a smaller sample of type-1 AGN. However, the presence of a bright optical nucleus in these objects – which had to be fitted simultaneously with the host profile – did not allow to robustly determine the Sérsic index but only to roughly characterise the host galaxies as either “disk-like” or “bulge-like”.

In terms of the surface brightness profile analysis, the absence of a nuclear point source in the optical images of our X-ray selected sample is a big advantage. Fig. 2 shows the Sérsic indices as a function of rest-frame $U-B$ color. The quiescent, X-ray-undetected sample (open symbols) shows a clear bimodality comprising blue galaxies with $n_{\text{ser}} \approx 1-2$ (disk-dominated) and red galaxies with $n_{\text{ser}} \geq 4$ (bulge-dominated). The bimodality is totally absent in the case of the “optically dull” / narrow-line AGN sample. This striking difference is probably a combination of three aspects: firstly, pure disk systems ($n_{\text{ser}} \approx 1$) are scarce in the AGN sample, which is a natural consequence of the SMBH mass-bulge mass correlation (e.g. Gebhardt et al. 2000; Ferrarese & Merritt 2000). Secondly, a significant fraction of the early-type AGN hosts show bluer colors than their quiescent counterparts, possibly due to recent or ongoing star formation. Thirdly, many hosts have intermediate Sérsic indices indicating a disk+bulge morphology and relatively red colors. A closer inspection reveals that the majority of these systems are observed edge-on, i.e. the red colors probably arise from intrinsic absorption in the plane of the disk component.

This interpretation is supported by Fig. 3, where the X-ray hardness ratio – defined as $(H + S)/(H - S)$, where S and H are the resp. fluxes in the $0.5 \dots 2$ keV and $2 \dots 10$ keV bands; large values of the hardness ratios indicate absorption – is shown as a function of X-ray luminosity. Most of the sources in the CDFS & E-CDFS at similar redshifts are distributed around a hardness

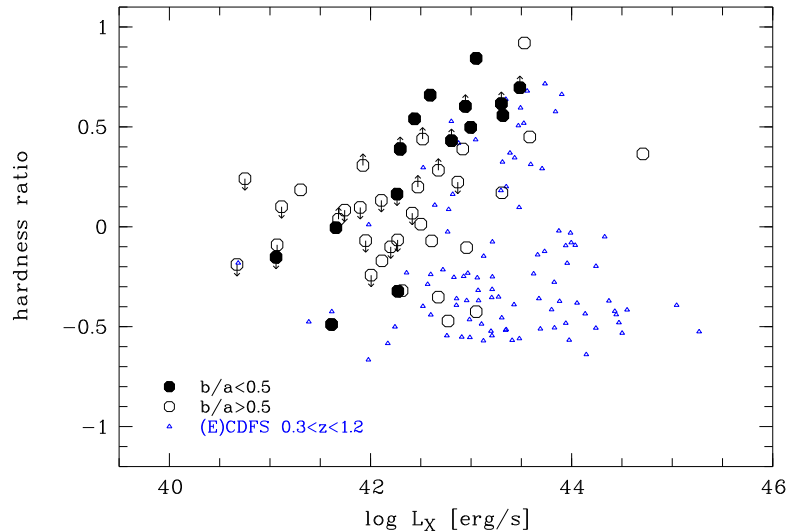


Figure 3. The X-ray hardness ratio as a function of X-ray luminosity. The large circles denote our X-ray selected AGN sample (solid and open circles represent edge-on and face-on galaxies, respectively), the small triangles show the other X-ray sources in the (Extended) Chandra Deep Field South at similar redshifts. Arrows indicate upper or lower limits on the hardness ratio.

ratio of approx. -0.5 , these are type-1 (broad-line) AGN. The majority of the objects in our sample show evidence for absorption, in particular those which have small axis ratios $b/a < 0.5$, hence are observed edge-on. The phenomenon of “optically dull” AGN could therefore partly be caused by absorbing material that is surrounding the nucleus out to scales of a kpc, thereby blocking the Narrow Line Region emission (Rigby et al. 2006 came to a similar conclusion using a smaller sample). However, Fig. 3 also shows that a fraction of the AGN hosts in our sample are observed relatively face-on and have moderate hardness ratios. Since the X-ray luminosities are also relatively low in most of these cases, the lack of an optical nucleus might be due to a relatively low black hole mass, a low accretion rate or even a truncated inner accretion disk.

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